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[3+2]-Cycloadditions of nitrilimines with heteroaryl thioketones

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ABSTRACT

The in situ-generated nitrilimines are trapped efficiently with heteroaryl thioketones bearing thiophen-2-yl or selenophen-2-yl substituents. The exclusive products observed in these reactions are 2,3-dihydro-1,3,4-thiadiazoles formed via regioselective [3+2]-cycloaddition. Competitive head-to-tail dimerization of the intermediate 1,3-dipoles was not observed in any of the studies reactions.

KEYWORDS

[3+2]-Cycloadditions; nitrilimines; thioketones; 1,3,4-thiadiazoles; X-ray crystallography

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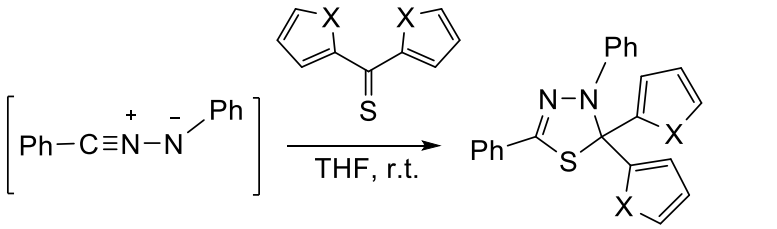
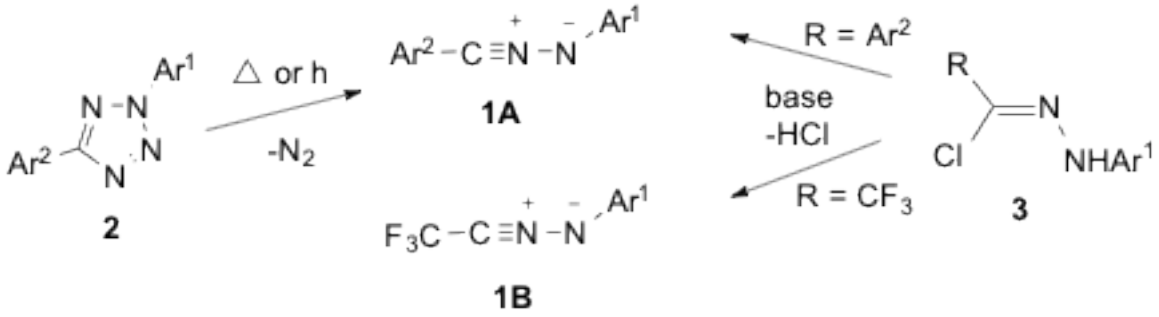
Graphical abstract



1. Introduction

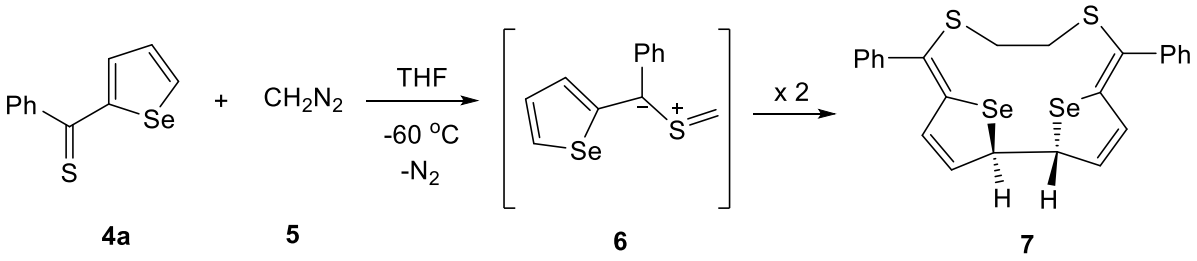
Nitrilimines **1** belong to the group of classical 1,3-dipoles widely applied in [3+2]-cycloadditions with diverse dipolarophiles, mainly activated ethenes, and acetylenes [1,2]. Synthetically important diarylnitrilimines **1A** are generated in situ by thermal or photolytical decomposition of 2,5-disubstituted tetrazoles **2** or by dehydrohalogenation of hydrazonoyl halides **3** in the presence of a base, e.g., triethylamine (TEA, Scheme 1). These reactive 1,3-dipoles have been characterized in a matrix at 12–85 K by UV and IR spectroscopy [3–5], and the structure of the sterically crowded *C*,*N*-ditritylnitrilimine was confirmed by X-ray crystallography [6]. Other relatively stable nitrilimines, bearing silyl or phosphorus substituents, are also known (e.g. [7–10]).



Scheme 1. Methods for generation of nitrilimines **1**.

Thioketones are known as 'superdipolarophiles' [11], and reactions of diarylnitrilimines **1A** with aromatic and cycloaliphatic representatives have been reported [12–15]. Moreover, other thiocarbonyl compounds were also used in cycloadditions with **1** [16–18]. In all cases, 2,3-dihydro-1,3,5-thiadiazoles were obtained in a regioselective manner. In a series of recent papers we reported on diverse cycloadditions using heteroaryl thioketones as dipolaro- and

dienophiles [19]. The studies showed that the presence of a heteroaryl substituent strongly modifies the reactivity of the thioketones. For example, the reaction of phenyl selenophen-2-yl thioketone (**4a**) with diazomethane (**5**) led to the 14-membered cyclodimer **7** of the intermediate thiocarbonyl *S*-methanide **6** via a biradical mechanism [20,21] (Scheme 2).



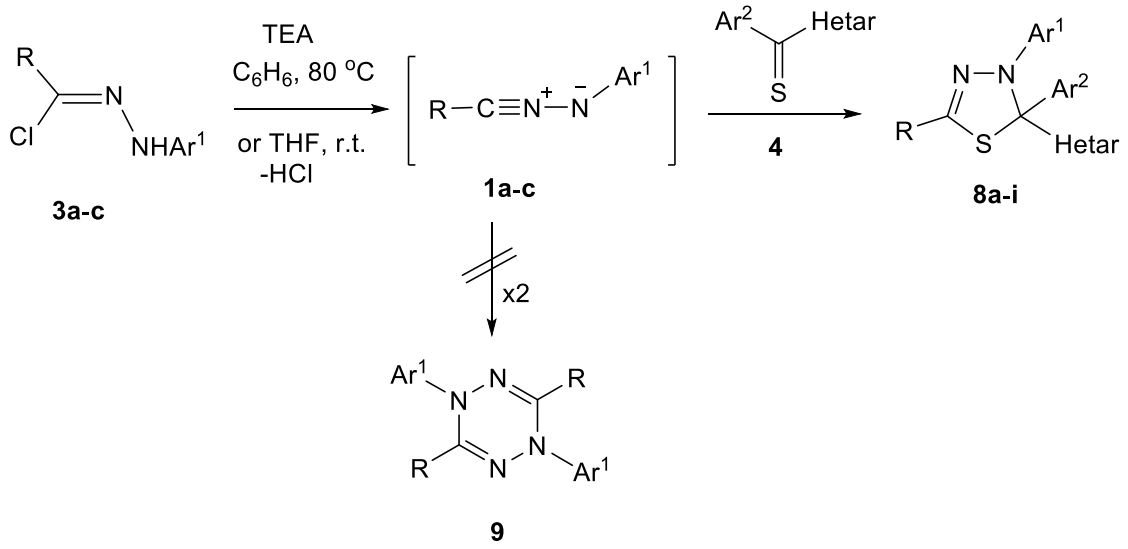
Scheme 2. Head-to-head dimerization of the selenophen-2-yl-substituted thiocarbonyl *S*-methanide **6**.

A very recent study demonstrated that in contrast to diarylnitrilimines **1A**, *N*-aryl-*C*-(trifluoromethyl)nitrilimines **1B** (Scheme 1), derived from trifluoroacetonitrile, react efficiently with thiochalcones as C=S dipolarophiles [22]. The same series of nitrilimines **1B** was used for the synthesis of trifluoromethyl-substituted 2,3-dihydro-1,3,4-thiadiazoles [23]. Considering the importance of these heterocycles [24,25], we have studied [3+2]-cycloadditions of heteroaryl thioketones with *C*,*N*-diphenyl-, *C*-acetyl-*N*-phenyl-, and *C*-ethoxycarbonyl-*N*-phenylnitrilimines (**1a**–**1c**).

2. Results and discussion

The reactions of the hydrazonoyl chlorides **3a**–**c** with heteroaryl thioketones **4** in the presence of an equimolar amount of TEA were performed either in boiling benzene or in THF at room temperature. Characteristically, the reaction times for diphenylnitrilimine (**1a**) were shorter than in the case of **1b** and **1c**. In general, the reactions in boiling benzene required 5–8 h, whereas the experiments in THF at room temperature were complete after 6 h for **1a** and 48 h in the cases of **1b** and **1c**. In a typical experiment with **1a** and phenyl selenophen-2-yl thioketone (**4a**) in THF, the green color of **4a** disappeared after 6 h. After typical workup by chromatography, the product formed was isolated as a yellow solid and characterized by means of spectroscopic methods. The ^{13}C NMR spectrum revealed the presence of the expected signals at 118.8 and 153.0 ppm attributed to C(2) and C(5), respectively, of the 2,3-

dihydro-1,3,5-thiadiazole ring. The molecular formula $C_{24}H_{18}N_2SSe$ for the [3+2]-cycloadduct **8a** was confirmed by elemental analysis (Scheme 3).



Scheme 3. [3+2]-Cycloadditions of the in situ-generated nitrilimines **1** with heteroaryl thioketones **4**.

Table 1. Synthesis of 2,3-dihydro-1,3,4-thiadiazoles **8** via [3+2]-cycloadditions.

Hydrazonoyl Chloride			Heteroaryl[a] thioketone			Thiadiazole **8**	Yield [%][b]
3	R	Ar^1	**4**	Ar^2	Hetar		
a	Ph	Ph	**a**	Ph	Sel	**a**	76[c]
a	Ph	Ph	**b**	Ph	Thi	**b**	72[d]
a	Ph	Ph	**c**	Sel	Sel	**c**	73[c]
a	Ph	Ph	**d**	Thi	Thi	**d**	71[d]
b	MeCO	Ph	**a**	Ph	Sel	**e**	67[c]
b	MeCO	Ph	**b**	Ph	Thi	**f**	66[c]
b	MeCO	Ph	**c**	Sel	Sel	**g**	72[c]
b	MeCO	Ph	**d**	Thi	Thi	**h**	72[d]
c	EtOCO	4-MeC_6H_4	**d**	Thi	Thi	**i**	72[d]

[a] Ph = Phenyl; Sel = Selenophen-2-yl; Thi = Thiophen-2-yl

[b] Yield of isolated product

[c] Reaction performed in THF at r.t.

[d] Reaction performed in boiling benzene

Similarly, the additional reactions performed with nitrilimines **1a**–**c** and heteroaryl thioketones **4a**–**d** afforded 2,3-dihydro-1,3,4-thiadiazoles **8b**–**i** in 66–76% yield (Table 1). All of these products displayed similar spectroscopic data, which confirmed the structure **8**. In addition, the structures of **8d** and **8h** were unambiguously confirmed by X-ray crystallography (Figure 1).

a) b)

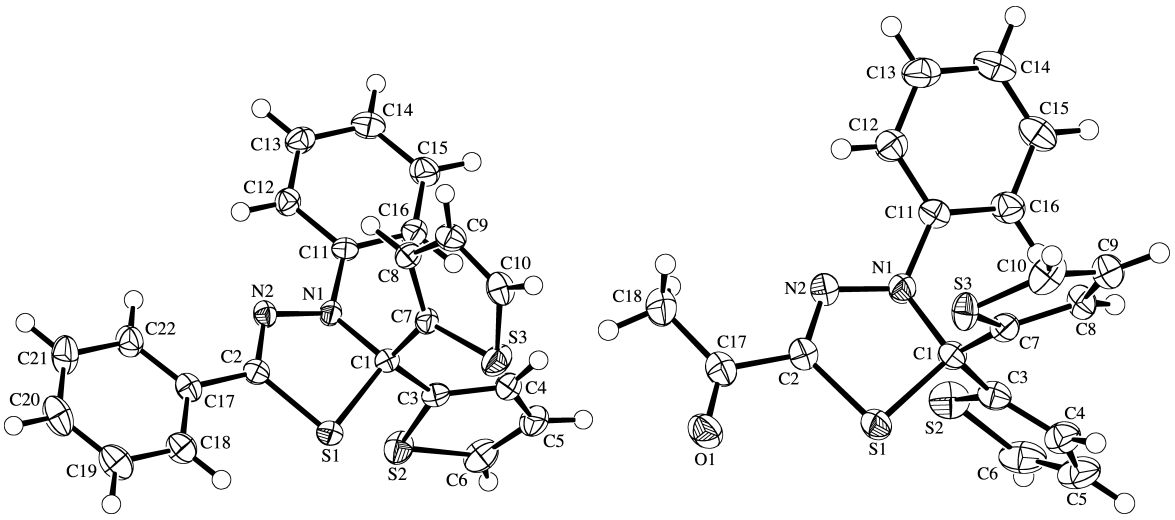


Figure 1. ORTEP plots [26] of the molecular structures of a) **8d** and b) one of the disordered conformations of **8h** (50 % probability ellipsoids; arbitrary numbering of the atoms).

The obtained products **8** were formed via regioselective [3+2]-cycloaddition of the initially generated nitrilimines **1** with thioketones **4** as dipolarophiles. In none of the studied cases were 1,3,4,6-tetrasubstituted 1,4-dihydro-1,2,4,5-tetrazines **9** observed, and this result demonstrated once more that heteroaryl thioketones are 'superdipolarophilic' agents. In reactions of **1a** with less reactive ethylenic or acetylenic dipolarophiles, the head-to-tail dimerization leading to **9** was reported as a process competitive with the [3+2]-cycloaddition [27,28].

In contrast to earlier reported formal [3+2]-cycloadditions of heteroaryl thioketones with thiocarbonyl *S*-methanides [29] or diazoalkanes [30], in which the sterically more crowded

1,3-dithiolanes were formed regioselectively, apparently, via an intermediate, delocalized diradical, the reactions with nitrilimines do not offer an experimental indication for a stepwise reaction mechanism. However, the structure of the obtained 1,3,4-thiadiazoles shows that also in this case, the postulated 1,5-diradical could be well stabilized as a likely intermediate within the delocalized system [23].

3. Conclusions

The study showed that heteroaryl thioketones are excellent trapping reagents for in situ-generated nitrilimines bearing phenyl, acetyl or ethoxycarbonyl groups at the C-atom. The 2,3-dihydro-1,3,4-thiadiazoles are formed in high yields in a regioselective manner, regardless of the type of substituents in the transient nitrilimines. In analogy to nitrilimines derived from trifluoroacetonitrile, the [3+2]-cycloadditions with heteroaryl thioketones occur without competitive dimerization of the nitrilimines used in this study.

4. Experimental design

4.1. General

Melting points were determined in a capillary using a Melt-Temp. II (*Aldrich*) apparatus, and they are uncorrected. The IR spectra were recorded on a Nexus FT-IR spectrophotometer as KBr pellets; absorptions in cm^{-1}. The ^{1}H and ^{13}C NMR spectra were measured in $CDCl_3$ solution on a Bruker Avance III instrument (600 and 150 MHz, resp.), using the solvent signal as reference. Chemical shifts (δ) are given in ppm and coupling constants *J* in Hz. The mass spectra were recorded on a Finnigan MAT-95 spectrometer. Elemental analyses were performed in the Microanalytical Laboratory of the Chemistry Faculty in Łódź or of the National Research Centre in Cairo. All crude mixtures were separated by chromatographic methods.

4.2. Starting materials

Aryl heteroaryl (**4a**,**b**) and diaryl thioketones (**4c**,**d**) were prepared following the literature procedures based on thionation of the corresponding ketones with Lawesson's reagent [31].

Hydrazonoyl chlorides **3a**–**c** were prepared either by reaction of the corresponding hydrazone with *N*-chlorosuccinimide-dimethyl sulfide complex according to the known general procedure [32] or by the reaction of aryl diazonium salts with α-chloro-β-ketoesters [33].

4.3. Reactions of thioketons 4 with hydrazonoyl chlorides 3 - General procedures

To a stirred solution of the corresponding thioketone **4** (1 mmol) in dry THF (5 mL), a solution of the appropriate hydrazonoyl chloride **3** (1 mmol) and 2.5 mL of triethylamine in 1 mL of dry THF was added dropwise at room temperature (r.t.) under an argon atmosphere. The resulting mixtures were kept at r.t. until the color of **4** disappeared completely. Triethylamine hydrochloride was filtered off and the solvent was evaporated under reduced pressure. The crude mixtures were purified chromatographically on silica gel using a mixture of petroleum ether with an increasing amount of dichloromethane. The obtained products **8** were additionally purified by crystallization from hexane or petroleum ether with a small amount of CH_2Cl_2.

In the alternative procedure (synthesis of **8b**,**d**,**h**,**i**), the reaction mixtures were refluxed in boiling dry benzene for 5–8 h. After completion of the reactions, the solvent was evaporated under reduced pressure and the obtained products were triturated with methanol to afford solid products (purified by crystallization from EtOH) or yellow-brown oils (purified by column chromatography (SiO_2), using the mixture AcOAEt/CH_2Cl_2 1:9 as the eluent.

4.3.1. 2,3-Dihydro-2,3,5-triphenyl-2-(selenophen-2-yl)-1,3,4-thiadiazole (8a)

Yellow crystals; m.p. 147–149°C (hexane/CH_2Cl_2); yield: 340 mg (76%). ^{1}H NMR: 6.90–6.94 (*m*, 1CH_{arom}); 7.11–7.18 (*m*, 5CH_{arom}); 7.25 (*dd*, $J_{H,H}$ = 3.8 Hz, $J_{H,H}$ = 1.0 Hz, 1CH_{arom}); 7.36–7.45 (*m*, 6CH_{arom}); 7.74–7.79 (*m*, 4CH_{arom}); 8.05 (*dd*, $J_{H,H}$ = 5.7 Hz, $J_{H,H}$ = 1.0 Hz, 1CH_{arom}). ^{13}C NMR: 90.3 (C(2)); 118.8, 121.9, 126.7, 127.8, 128.2, 128.3, 128.5, 128.6, 128.9, 129.5, 131.9, 134.0 (18CH_{arom}); 131.2, 141.7, 143.4, 153.0 (4C_{arom}, C=N). IR (KBr): 3063*m*, 3022*m*, 1594*s*, 1553m, 1492*s*, 1445*m*, 1328*s*, 1255*s*, 1236*s*, 1122*m*, 1065*m*, 967*s*, 742*s*, 698*s*, 685*s*. Anal. calcd for $C_{24}H_{18}N_2SSe$ (445.44): C 64.71, H 4.07, N 6.29, S 7.20; found: C 64.72, H 4.04, N 6.31, S 7.37.

4.3.2. 2,3-Dihydro-2,3,5-triphenyl-2-(thiophen-2-yl)-1,3,4-thiadiazole (8b)

Yellow crystals; m.p. 136–138°C (petroleum ether/CH_2Cl_2); yield: 286 mg (72%). ^{1}H NMR: 6.76–6.79 (*m*, 2CH_{arom}); 6.95 (*dd*, $J_{H,H}$ = 3.7 Hz, $J_{H,H}$ = 1.1 Hz, 1CH_{arom}); 6.96–7.00 (*m*, 4CH_{arom}); 7.21 (*dd*, $J_{H,H}$ = 5.1 Hz, $J_{H,H}$ = 1.1 Hz, 1CH_{arom}); 7.24–7.31 (*m*, 6CH_{arom}); 7.60–7.64 (*m*, 4CH_{arom}). ^{13}C NMR: 88.3 (C(2)); 118.6, 121.7, 126.2, 126.6, 127.6, 127.9, 128.1 128.3, 128.4, 128.5, 129.4, 129.8 (18CH_{arom}); 131.2, 141.7, 141.78, 143.4, 145.6 (4C_{arom}, C=N). IR (KBr): 3079*m*, 3018*m*, 1595*s*, 1553*m*, 1496*vs*, 1448*m*, 1337*s*, 1325*s*, 1255*s*, 1236*s*, 1125*s*, 1068*m*, 967*s*, 821*m*, 739*s*, 720*s*, 685*s*. MS *m/z* (%): 398 [M^+] (75), 391 (15), 377 (17), 365 (15), 145 (100), 102 (50). Anal. calcd for $C_{24}H_{18}N_2S_2$ (398.54): C 72.33, H 4.55, N 7.03, S 16.09; found: C 72.34, H 4.57, N 7.02, S 15.92.

4.3.3. 2,3-Dihydro-3,5-diphenyl-2,2-di(selenophen-2-yl)-1,3,4-thiadiazole (8c)

Yellow crystals; m.p. 115–117°C (petroleum ether/CH_2Cl_2); yield: 365 mg (73%). ^{1}H NMR: 6.98–7.00 (*m*, 1CH_{arom}); 7.14–7.19 (*m*, 4CH_{arom}); 7.25–7.27 (*m*, 2CH_{arom}); 7.34 (*dd*, $J_{H,H}$ = 3.9 Hz, $J_{H,H}$ = 1.0 Hz, 2CH_{arom}); 7.41–7.46 (*m*, 3CH_{arom}); 7.75–7.78 (*m*, 2CH_{arom}); 8.09 (*dd*, $J_{H,H}$ = 5.7 Hz, $J_{H,H}$ = 1.4 Hz, 2CH_{arom}). ^{13}C NMR: 89.6 (C(2)); 120.7, 123.3, 126.8, 128.2, 128.7, 129.2, 129.7, 130.7, 133.8 (16CH_{arom}); 131.1, 142.4, 143.4, 153.2 (4C_{arom}, C=N). IR (KBr): 3056*m*, 3015*m*, 1594*s*, 1556*m*, 1489*s*, 1445*m*, 1318*s*, 1252*s*, 1239*s*, 1116*s*, 1059*m*, 960*m*, 875*m*, 758*s*, 745*s*, 701*s*, 691*s*, 682*s*. Anal. calcd for $C_{22}H_{16}N_2SSe_2$ (498.36): C 53.02, H 3.24, N 5.62, S 6.43; found: C 53.02, H 3.22, N 5.55, S 6.38.

4.3.4. 2,3-Dihydro-3,5-diphenyl-2,2-di(thiophen-2-yl)-1,3,4-thiadiazole (8d)

Yellow crystals; m.p. 119–121°C; yield: 287 mg (71%). ^{1}H NMR: 6.92–7.00 (*m*, 2CH_{arom}); 7.13–7.23 (*m*, 5CH_{arom}); 7.39 (*dd*, $J_{H,H}$ = 4.9 Hz, $J_{H,H}$ = 1.0 Hz, 1CH_{arom}); 7.42–7.46 (*m*, 2CH_{arom}); 7.77 (*d*, $J_{H,H}$ = 6.7 Hz, 1CH_{arom}). ^{13}C NMR: 86.1 (C(2)), 120.3, 123.1, 126.7, 126.8, 127.8, 128.2, 128.5, 128.7, 129.7 (16CH_{arom}); 131.2, 142.4, 143.4, 146.1 (4C_{arom}, C=N). IR (KBr): 3075*m*, 3018*m*, 1591*s*, 1559*m*, 1489*s*, 1448*m*, 1426*m*, 1328*s*, 1249*s*, 1236*s*, 1182*m*, 1122*s*, 1065*m*, 1036*m*, 960*s*, 878*m*, 843*m*, 739*s*, 701*vs*, 682*s*. MS *m/z* (%): 404 [M^+] (100). Anal. calcd for $C_{22}H_{16}N_2S_3$ (404.57): C 65.31, H 3.99, N 6.92, S 23.78; found: C 65.20, H 4.17, N 6.91, S 23.80.

4.3.5. 1-[4,5-Dihydro-4,5-diphenyl-5-(selenophen-2-yl)-1,3,4-thiadiazol-2-yl]ethanone (8e)

Yellow-brown crystals; m.p. 110–112°C (hexane/CH_2Cl_2); yield: 275 mg (67%). ^{1}H NMR: 2.63 (*s*, CH_3); 7.00–7.04 (*m*, $1CH_{arom}$); 7.12–7.18 (*m*, $5CH_{arom}$); 7.21 (*dd*, $J_{H,H}$ = 3.8 Hz, $J_{H,H}$ = 1.0 Hz, $1CH_{arom}$); 7.39–7.45 (*m*, $3CH_{arom}$); 7.66–7.69 (*m*, $2CH_{arom}$); 8.09 (*dd*, $J_{H,H}$ = 5.8 Hz, $J_{H,H}$ = 1.0 Hz, $1CH_{arom}$). ^{13}C NMR: 26.7 (CH_3); 91.8 (C(2')); 119.8, 123.9, 127.2, 128.4, 128.6, 128.7, 129.0, 132.3, 134.9 ($13CH_{arom}$); 141.6, 141.7, 142.1, 152.2 ($3C_{arom}$, C=N); 191.0 (C=O). IR (KBr): 3060*m*, 3031*m*, 1666*vs* (C=O), 1591*s*, 1527s, 1489*s*, 1439*m*, 1252*vs*, 1144*vs*, 1046*s*, 932*s*, 748*s*, 691*s*. Anal. calcd for $C_{20}H_{16}N_2OSSe$ (411.38): C 58.39, H 3.92, N 6.81, S 7.79; found: C 58.40, H 3.93, N 6.82, S 7.87.

4.3.6. 1-[4,5-Dihydro-4,5-diphenyl-5-(thiophen-2-yl)-1,3,4-thiadiazol-2-yl]ethanone (8f)

Yellow crystals; m.p. 113–115°C (hexane/CH_2Cl_2); yield: 240 mg (66%). ^{1}H NMR: 2.61 (*s*, CH_3); 6.90 (*dd*, $J_{H,H}$ = 5.0 Hz, $J_{H,H}$ = 3.7 Hz, $1CH_{arom}$); 6.98–7.02 (*m*, $1CH_{arom}$); 7.06 (*dd*, $J_{H,H}$ = 3.7 Hz, $J_{H,H}$ = 1.1 Hz, $1CH_{arom}$); 7.14–7.16 (*m*, $4CH_{arom}$); 7.36 (*dd*, $J_{H,H}$ = 5.0 Hz, $J_{H,H}$ = 1.1 Hz, $1CH_{arom}$); 7.37–7.46 (*m*, $3CH_{arom}$); 7.63–7.65 (*m*, $2CH_{arom}$). ^{13}C NMR: 25.7 (CH_3); 89.8 (C(2')); 115.4, 119.6, 123.8, 126.5, 128.4, 128.6, 128.7, 129.5, 130.2 ($13CH_{arom}$); 141.6, 141.7, 142.2, 145.0 ($3C_{arom}$ and C=N); 191.0 (C=O). IR (KBr): 3066*m*, 3031*m*, 1670*vs* (C=O), 1591*s*, 1530s, 1492*s*, 1442*m*, 1252*vs*, 1144*vs*, 1049*s*, 932*s*, 821*m*, 748*s*, 720*s*, 691*s*. Anal. calcd for $C_{20}H_{16}N_2OS_2$ (364.48): C 65.91, H 4.42, N 7.69, S 17.59; found: C 65.82, H 4.67, N 7.72, S 17.70.

4.3.7. 1-[4,5-Dihydro-4-phenyl-5,5-di(selenophen-2-yl)-1,3,4-thiadiazol-2-yl]ethanone (8g)

Orange crystals; m.p. 116–118°C (petroleum ether/CH_2Cl_2); yield: 335 mg (72%). ^{1}H NMR: 2.61 (CH_3); 7.06–7.10 (*m*, $1CH_{arom}$); 7.17–7.20 (*m*, $4CH_{arom}$); 7.22–7.24 (*m*, $2CH_{arom}$); 7.32 (*dd*, $J_{H,H}$ = 3.9 Hz, $J_{H,H}$ = 1.0 Hz, $2CH_{arom}$); 8.12 (*d*, $J_{H,H}$ = 5.6 Hz, $2CH_{arom}$). ^{13}C NMR: 25.7 (CH_3); 91.2 (C(2')); 121.2, 124.9, 128.5, 129.3, 130.8, 134.5 ($11CH_{arom}$); 141.5, 142.3, 152.7 ($3C_{arom}$, C=N); 191.1 (C=O). IR (KBr): 3107*m*, 3056*m*, 1670*vs* (C=O), 1593*m*, 1530*s*, 1486*s*, 1239*vs*, 1223*s*, 1141*s*, 1049*m*, 1021*m*, 922*m*, 891*m*, 761*m*, 701*s*. Anal. calcd for $C_{18}H_{14}N_2OSSe_2$ (464.30): C 46.56, H 3.04, N 6.03, S 6.91; found: C 46.75, H 3.03, N 6.07, S 6.92.

4.3.8. 1-[4,5-Dihydro-4-phenyl-5,5-di(thiophen-2-yl)-1,3,4-thiadiazol-2-yl]ethanone (8h)

Yellow crystals; m.p. 130–132°C (EtOH); yield: 265 mg (72%). ^{1}H NMR: 2.57 (*s*, CH_3); 6.92–6.96 (*m*, $2CH_{arom}$); 7.04–7.08 (*m*, $1CH_{arom}$); 7.12–7.18 (*m*, $4CH_{arom}$); 7.20–7.23 (*m*, $1CH_{arom}$); 7.41 (*d*, $J_{H,H}$ = 5.0 Hz, $1CH_{arom}$); 7.72 (*d*, $J_{H,H}$ = 5.0 Hz, $1CH_{arom}$); 7.94 (*d*, $J_{H,H}$ = 3.7 Hz, $1CH_{arom}$). ^{13}C NMR: 25.7 (CH_3); 87.3 (C(2')); 120.8, 124.7, 126.8, 128.3, 128.4, 128.6, 141.5, 142.4, 145.6 ($11CH_{arom}$, $3C_{arom}$, C=N); 191.1 (C=O). IR (KBr): 3085*m*, 1665*s* (C=O), 1533*s*, 1490*m*, 1240*s*, 1226*s*, 1137*s*, 1043*m*, 925*m*, 755*m*, 719*s*, 696*m*. MS *m/z* (%): 370 [M^+] (100). Anal. calcd. for: $C_{18}H_{14}N_2OS_3$ (370.51): C 58.35, H 3.81, N 7.56, S 25.96; found: C 58.32, H 3.85, N 7.51, S 25.94.

4.3.9. Ethyl 4,5-dihydro-5,5-di(thiophen-2-yl)-4-(p-tolyl)-1,3,4-thiadiazole-2-carboxylate (8i)

Yellow-brown oil (AcOEt/CH_2Cl_2 1:9); yield: 300 mg (72%). ^{1}H NMR: 1.36 (*t*, $J_{H,H}$ = 7.1 Hz, CH_3), 2.22 (*s*, CH_3), 4.35 (*q*, $J_{H,H}$ = 7.1 Hz, CH_2O), 6.89–6.92 (*m*, $3CH_{arom}$); 6.95–6.98 (*m*, $2CH_{arom}$); 7.10 (*dd*, $J_{H,H}$ = 3.7 Hz, $J_{H,H}$ = 1.1 Hz, $1CH_{arom}$); 7.18 (*dd*, $J_{H,H}$ = 4.9 Hz, $J_{H,H}$ = 3.9 Hz, $1CH_{arom}$); 7.37 (*dd*, $J_{H,H}$ = 5.1 Hz, $J_{H,H}$ = 1.1 Hz, $1CH_{arom}$); 7.68 (*dd*, $J_{H,H}$ = 4.9 Hz, $J_{H,H}$ = 1.1 Hz, $1CH_{arom}$); 7.90 (*dd*, $J_{H,H}$ = 3.7 Hz, $J_{H,H}$ = 1.1 Hz, $1CH_{arom}$). ^{13}C NMR: 14.1 (CH_3); 20.8 (CH_3); 62.3 (CH_2O); 87.5 (C(2')), 114.5, 121.3, 126.8, 127.9 128.3, 128.5, 133.2, 133.4 ($10CH_{arom}$); 134.8, 139.4, 143.0, 145.7, 160.3 ($4C_{arom}$, C=N); 178.8 (C=O). IR (KBr): 2962*m*, 2923*m*, 1730*s* and 1704*s* (C=O), 1541s, 1507*s*, 1463*s*, 1261*vs*, 1090*vs*, 1073*m*, 804*s*, 708*m*. MS *m/z* (%): 414 [M^+] (100). Anal. calcd for $C_{20}H_{18}N_2O_2S_3$ (414.56): C 57.94, H 4.38, N 6.76, S, 23.20; found: C 57.97, H 4.35, N 6.70, S 23.19.

4.4. X-Ray Crystal Structure Determination of Compounds 8d and 8h [34]

All measurements were made on *Nonius KappaCCD* area-detector diffractometer [35] using Mo*K*a radiation (λ = 0.71073 Å) and an *Oxford Cryosystems Cryostream 700* cooler. The data collection and refinement parameters are given below [34] and views of the molecules are shown in Figure 1. Data reduction was performed with *HKL Denzo and Scalepack* [36]. The intensities were corrected for Lorentz and polarization effects, and an absorption correction based on the multi-scan method [37] was applied. Equivalent reflections were merged. Each

structure was solved by direct methods using *SHELXS97* [38], which revealed the positions of all non-hydrogen atoms. In the case of **8h**, one of the five-membered rings is disordered through a rotation of approximately 180° about the ring pivot axis, thus interchanging the positions of the *S*-atom and a *C*-atom. Two positions were defined for each of these atoms and the site occupation factor of the major conformation refined to 0.697(2). Similarity restraints were applied to the chemically equivalent bond lengths involving disordered atoms, while the neighboring disordered atoms were restrained to have similar atomic displacement parameters. The non-hydrogen atoms were refined anisotropically. All of the H-atoms were placed in geometrically calculated positions and refined by using a riding model where each *H*-atom was assigned a fixed isotropic displacement parameter with a value equal to $1.2U_{eq}$ of its parent atom ($1.5U_{eq}$ for the methyl group in **8h**). The refinement of each structure was carried out on F^2 by using full-matrix least-squares procedures, which minimized the function $\Sigma w(F_o^2 - F_c^2)^2$. A correction for secondary extinction was applied in the case of **8h**. Neutral atom scattering factors for non-H-atoms were taken from ref. [39], and the scattering factors for *H*-atoms were taken from ref. [40]. Anomalous dispersion effects were included in F_c [41]; the values for f' and f'' were those of ref. [42]. The values of the mass attenuation coefficients are those of ref. [43]. The *SHELXL*-2016 program [44] was used for all calculations.

Crystal data for **8d**: $C_{22}H_{16}N_2S_3$, M = 404.55, crystallized from Et_2O/CH_2Cl_2, yellow, prism, crystal dimensions 0.12 × 0.20 × 0.28 mm, triclinic, space group $P\bar{1}$, Z = 2, reflections for cell determination 33649, 2θ range for cell determination 4–55°, a = 9.0252(2) Å, b = 10.2253(2) Å, c = 11.6650(3) Å, α = 94.8910(16), β = 110.1558(15), γ = 108.0826(16)°, V = 938.12(4) Å^3, T = 160(1) K, D_X = 1.432 g·cm^{-3}, μ(Mo$K\alpha$) = 0.405 mm^{-1}, scan type ω, $2\theta_{(max)}$ = 54.9°, transmission factors (min; max) = 0.863; 0.955, total reflections measured 20152, symmetry independent reflections 4267, reflections with $I > 2\sigma(I)$ 3135, reflections used in refinement 4267, parameters refined 244, $R(F)$ [$I > 2\sigma(I)$ reflections] = 0.0433, $wR(F^2)$ [all data] = 0.1099 ($w = [\sigma^2(F_o^2) + (0.0469P)^2 + 0.4391P]^{-1}$, where $P = (F_o^2+2F_c^2)/3$), goodness of fit 1.068, final Δ_{max}/σ 0.000, $\Delta\rho$ (max; min) = 0.38; –0.44 e Å^{-3}.

Crystal data for **8h**: $C_{18}H_{14}N_2OS_3$, M = 370.49, crystallized from hexane/CH_2Cl_2, yellow, plate, crystal dimensions 0.07 × 0.22 × 0.37 mm, monoclinic, space group $P2_1/c$, Z = 4, reflections for cell determination 61174, 2θ range for cell determination 4–55°, a = 10.6525(1) Å, b = 15.9217(2) Å, c = 10.3570(2) Å, β = 104.7834(9), V = 1698.46(4) Å^3, T =

160(1) K, D_X = 1.449 g·cm^{-3}, μ(Mo$K\alpha$) = 0.444 mm^{-1}, scan type ω, $2\theta_{(max)}$ = 54.9°, transmission factors (min; max) = 0.890; 0.970, total reflections measured 40626, symmetry independent reflections 3892, reflections with $I > 2\sigma(I)$ 3248, reflections used in refinement 3892, parameters refined 238, restraints 54, $R(F)$ [$I > 2\sigma(I)$ reflections] = 0.0352, $wR(F^2)$ [all data] = 0.0926 ($w = [\sigma^2(F_o^2) + (0.0427P)^2 + 0.8503P]^{-1}$, where $P = (F_o^2+2F_c^2)/3$), goodness of fit 1.044, secondary extinction coefficient 0.006(1), final Δ_{max}/σ 0.001, $\Delta\rho$ (max; min) = 0.37; –0.48 e Å^{-3}.

Disclosure statement

No potential conflict of interest was reported by the authors.

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